

TABLE 2

Surface Treatment	PETG/PDMS	PS/PDMS
1 M NaOH	$5 \pm 1 \times 10^{-4}$	
3 Layer PEM	$-1.8 \pm 0.3 \times 10^{-4}$	
4 Layer PEM	$4.2 \pm 0.2 \times 10^{-4}$	
13 Layer PEM	$-1.7 \pm 0.3 \times 10^{-4}$	$-1.3 \pm 0.2 \times 10^{-4}$
14 Layer PEM	$4.8 \pm 0.5 \times 10^{-4}$	$4.1 \pm 0.2 \times 10^{-4}$

Table 2 summarizes the EOF mobility ($\text{cm}^2/\text{V}\cdot\text{S}$) of various non-limiting illustrative examples of PEM derivatized microchannels made in substrates of PETG or PS with PDMS lids. From Tables 1 and 2, as will become clear to one of ordinary skill, PEMs composed of 13 or 14 layers results in microchannels with similar mobilities in PETG and PS substrates despite differences in mobility of their respective, native plastics. Consequently, the present method of surface derivatization with PEMs can produce similar surfaces on different plastic materials thereby allowing flexibility in substrate polymer selection for a given or desired application.

EOF mobility is also affected by the native negative surface charge of the lids when the lid is not derivatized **22**, **122**. For example, the net flow rate is slower in microchannels formed in either PETG or PS substrates with PEMs having a positive PAH layer **30** as its top or outermost layer using either PETG or PS substrates with an uncoated PDMS lid. Conversely, in negatively charged microchannels (i.e., microchannels with a negatively charged top or outermost layer), there is an increase in net flow due to the native negative charge on the PDMS lids **22**, **122**. Therefore, the native negative charge of the PDMS lid increases the net flow in the microchannels with the negatively charged PSS top or outermost layer, and decrease the net flow in microchannels with the positively charged PAH layer.

One significant practical advantage of the PEM coated microchannels is the ease with which the microchannels may be filled with a liquid as compared with untreated plastics. The hydrophilic character of the PEMs facilitates wetting of the microchannel surfaces.

Further, unlike using uncoated (i.e., native) plastic substrates the PEMs coated microchannels of the present invention do not require priming and associated problems therewith. Using the PEM coated microchannels, priming may not be necessary and air bubbles do not get pinned to the walls on the PEM coated microchannel surfaces during filling. Consequently, there is a reduction in time required to prepare the microchannels for use and may facilitate the use of plastic microchannels for a wider variety of applications.

A further advantage of PEM coated channels is the ability to regenerate the outermost layer after use or exposure by flowing the final polyelectrolyte solution through the microchannel. For example, if PSS layer **32**, **132** is the top, outermost layer of microchannel **14**, **114**, a solution comprising PSS can be re-applied to microchannels **14**, **114**. The PSS is allowed to adsorb to the microchannel surfaces thereby regenerating the top layer.

In one specific, further embodiment, various molecules are immobilized in or on the PEMs. The molecules may include, but are not limited to proteins, antibodies and DNA. These molecules may be immobilized in the PEMs by adding the molecules to the desired PAH and PSS solutions during PAH and PSS layer deposition. Alternatively, or in addition, the desired molecules could be introduced into a derivatized microchannel, i.e. after PEMs deposition is

complete. Even if the desired molecules are introduced to the outermost surface of the PEMs, the molecules may diffuse from the outermost layer to one or more inner layers.

Furthermore, the PEMs layers may be used to provide biocompatible microchannels by decreasing the adsorption of biological species.

Further illustration of the use of PEMs to control or alter EOF is provided in reference to a microfluidic device **210** depicted in FIGS. **2(a)**–**2(c)**. As described above, since the direction of the EOF is determined by the charge on a substrate surface, selective deposition of PEMs on various selected surfaces of microchannel **214** along with the application of a controlled voltage can be used to direct the flow in microfluidic devices such as microfluidic device **210**.

Microchannel **214** comprises a subchannel **215** in which a portion of the channel surface **216** has PEMs **228**, **232** with a top or outermost layer comprising a PSS layer **232** and a different portion of the channel surface **218** has PEMs **229** with outermost surface comprising a PAH layer **229**, **230**. The surfaces of subchannel **215** were treated by exposing the microchannel **214** to alternating solutions of positively and negatively charged polyelectrolytes to form the desired PEMs, as described above with reference to microchannels **14**, **114**. The substrate **215** may be composed of a variety of polymeric materials including but not limited to polystyrene or PMMA. The microchannel **214** may be covered with a lid (not shown). Laminar flow patterning is used to fill one half of the microchannel **214** with a positively charged PAH solution and the other half with water as depicted in FIG. **2(a)**. Further details on the laminar flow patterning may be made by reference to Kenis, P. K., et al., *Science* 1999, 285, 83, herein incorporated by reference.

As a result, one half of the microchannel **214** comprises a positively charged PAH layer **230** as the outermost surface of PEMs **229** as shown in FIG. **2(c)**. The other half of the microchannel **214** is oppositely charged comprising negatively charged PSS layer **232** on outermost surface of PEMs **228** as shown in FIG. **2(c)**. The division of the microchannel **214** into two oppositely charged halves is indicated by a dotted line **240**.

While FIGS. **2(a)**–**2(c)** depict coating a microchannel **214** by selectively depositing a positive PAH layer over one half of the microchannel **214** surfaces, it should be readily apparent to one of ordinary skill that selective deposition of a negatively charged PSS layer may be formed over selected microchannel surfaces comprising a previously deposited positively charge layer.

The derivatized microchannel **214** results in a bi-directional electroosmotic flow within a single subchannel **215** (FIG. **2(b)**). Specifically, the flow of a fluid on the PSS derivatized side (i.e., microchannel surfaces with outermost surface **232** disposed thereon) moved from anode to cathode indicating positive velocities while flow in the PAH derivatized side (i.e., microchannel surfaces with outermost surface **230** disposed thereon) was from cathode to anode indicating negative velocities. Thus, side-by-side bi-directional flow is provided in a single microchannel as described in detail in Barker et al. *Anal. Chem.* 2000.

In an alternative embodiment, opposite electroosmotic flow directions in the same microchannel may be achieved using a positively derivatized microchannel with a negatively charged lid thereby achieving top-bottom opposite flows.

Complex flow patterns within a microchannel is next described with reference to FIGS. **3(a)**–**2(e)**. FIGS. **3(a)**–**3(e)** depict five microchannels, each formed of two subchan-